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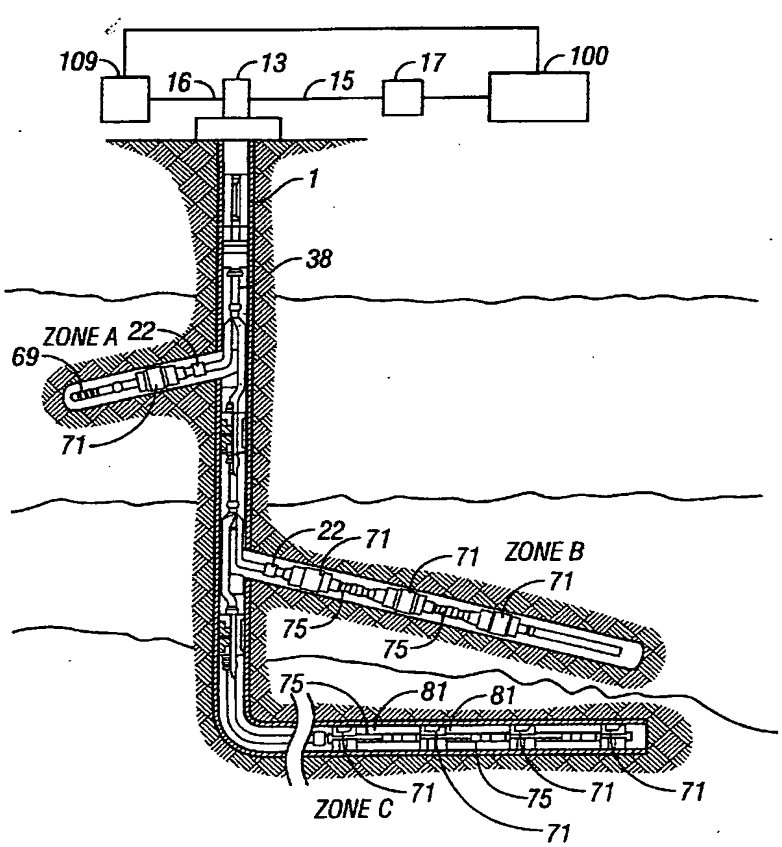
(54) **Title:** OPTICAL POSITION SENSING FOR WELL CONTROL TOOLS



(57) **Abstract:** An apparatus and methods are disclosed for using optical sensors to determine the position of a movable flow control element in a well control tool. A housing has a movable element disposed within such that the element movement controls the flow through the tool. An optical sensing system senses the movement of the element. Optical sensors are employed that use Bragg grating reflections, time domain reflectometry, and line scanning techniques to determine the element position. A surface or downhole processor is used to interpret the sensor signals.

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OPTICAL POSITION SENSING FOR WELL CONTROL TOOLS

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CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority of U.S. Provisional Application No. 60/332,478 filed on November 14, 2001.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to a method for the control of oil and gas production wells. More particularly, it relates to an optical position sensor system for determining the position of movable elements in well production equipment.

Description of the Related Art

The control of oil and gas production wells constitutes an on-going concern of the petroleum industry due, in part, to the enormous monetary expense involved as well as the risks associated with environmental and safety issues.

Production well control has become particularly important and more complex in view of the industry wide recognition that wells having multiple branches (i.e., multilateral wells) will be increasingly important and commonplace. Such multilateral wells include discrete production zones which produce fluid in either common or discrete production tubing. In either case, there is a need for controlling zone production, isolating specific zones and otherwise monitoring each zone in a particular well. Flow control devices such as sliding sleeve valves, packers, downhole safety valves, downhole chokes, and downhole tool stop systems are commonly used to control flow between the production tubing and the casing annulus. Such devices are used for zonal isolation, selective production, flow shut-off, commingling production, and transient testing.

These tools are typically actuated by hydraulic systems or electric motors driving a member axially with respect to a tool housing. Hydraulic actuation can be implemented with a shifting tool lowered into the tool on a wireline or by running

hydraulic lines from the surface to the downhole tool. Electric motor driven actuators may be used in intelligent completion systems controlled from the surface or using downhole controllers.

The surface controllers are often hardwired to downhole sensors which transmit information to the surface such as pressure, temperature and flow. With multiple production zones intermingled in the single well bore, it is difficult to determine the operation and performance of individual downhole tools from surface measurements alone. It is also desirable to know the position of the movable members, such as the sliding sleeve in a sliding sleeve valve, in order to better control the flow from various zones. Originally, sliding sleeves were actuated to either a fully open or fully closed position. Surface controlled hydraulic sliding sleeves such as Baker Oil Tools Product Family H81134 provides variable position control of the sleeve which allows for continuous flow control of the zone of interest. In order to efficiently utilize this control capability, a sensor system is needed to determine the position of the sleeve. Position data is then processed at the surface by the computerized control system and is used for control of the production well. Similar position data will enhance the efficient flow control of the other downhole tools mentioned. In addition, for critical tools, such as downhole safety valves, indication of the position, or setting, of the valve is desired to ensure that the valve is operating properly.

Thus there is a need for a position sensing system which can monitor the operating configuration of downhole tools by measuring the position of a movable member over a large displacement range.

SUMMARY OF THE INVENTION

The methods and apparatus of the present invention overcome the foregoing disadvantages of the prior art by providing a reliable method of sensing the position of a movable member in a downhole tool including, but not limited to, a sliding sleeve production valve, a safety valve, and a downhole choke.

The present invention contemplates an apparatus for and method of using optical position sensors to determine the position of a movable flow control member

in a downhole flow control tool such as a sliding sleeve, production valve safety valve, or the like.

In one preferred embodiment, this invention provides a system for controlling a downhole flow, comprising a flow control device in a tubing string in a well. The flow control device has a first member engaged with the tubing string and a second member moveable with respect to the first member, and acting cooperatively with the first member for controlling the downhole flow through the flow control device. An optical position sensing system acts cooperatively with the first member and the second member for detecting a position of the second member relative to the first member and generating at least one signal related thereto. A controller receives the at least one signal and determines, according to programmed instructions, the position of the second member relative to the first member and controls the downhole flow in response thereto.

A method is provided for determining the position of a movable flow control member in a well flow control tool, comprising sensing the position of the flow control member using an optical position sensing system and generating a signal related to the flow control member position. The signal is transmitted to a controller. The position of the flow control member is determined according to programmed instructions.

Examples of the more important features of the invention thus have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

Fig. 1 is a diagrammatic view depicting a multizone completion with an optical position sensing system according to one embodiment of the present invention;

Fig. 2 is a diagrammatic view of a section of a sliding sleeve valve with fiber optic sensors according to one embodiment of the present invention;

Fig. 3a-d is a schematic diagram of a Bragg grating disposed in an optical fiber according to one embodiment of the present invention;

Fig. 4 is a schematic diagram of a sliding sleeve valve two position fiber optic position sensor using Bragg gratings according to one embodiment of the present invention;

Fig. 5 is a schematic diagram of a sliding sleeve valve multiple position fiber optic position sensor using Bragg gratings according to one embodiment of the present invention;

Fig. 6 is a schematic diagram of an alternative sliding sleeve valve multiple position fiber optic position sensor using Bragg gratings according to one embodiment of the present invention;

Fig. 7 is a schematic diagram of a second alternative sliding sleeve valve multiple position fiber optic position sensor using Bragg gratings according to one embodiment of the present invention;

Fig. 8 is a schematic diagram of a sliding sleeve valve multiple position fiber optic position sensor using optical time domain reflection techniques according to one embodiment of the present invention;

Fig. 9 is a schematic diagram of an alternative sliding sleeve valve multiple position fiber optic position sensor using optical time domain reflection techniques according to one embodiment of the present invention;

Fig. 10 is a schematic diagram of a well control tool with an optical senor system, according to one embodiment of the present invention;

Fig. 11 is a schematic of a preferred marking pattern for determining position according to one embodiment of the present invention;

Fig. 12 is a schematic of an preferred grating pattern according to one embodiment of the present invention; and,

Fig. 13 is a schematic showing an optical-magnetic technique fiber optic position sensing technique according to one embodiment of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

As is known, a given well may be divided into a plurality of separate zones which are required to isolate specific areas of a well for purposes of producing selected fluids, preventing blowouts and preventing water intake. A particularly significant contemporary feature of well production is the drilling and completion of lateral or branch wells which extend from a particular primary wellbore. These lateral or branch wells can be completed such that each lateral well constitutes a separable zone and can be isolated for selected production.

With reference to **FIG. 1**, well **1** includes three zones, namely zone **A**, zone B and zone **C**. Each of zones **A, B** and **C** have been completed in a known manner.

In zone **A**, a slotted liner completion is shown at **69** associated with a packer **71**. In zone **B**, an open hole completion is shown with a series of packers **71** and sliding sleeve **75**, also called a sliding sleeve valve. In zone **C**, a cased hole completion is shown again with the series of packers **71**, sliding sleeve **75**, and perforating tools **81**. The packers **71** seal off the annulus between the wellbores and the sliding sleeve **75** thereby constraining formation fluid to flow only through an open sliding sleeve **75**. The completion string **38** is connected at the surface to wellhead **13**.

In a preferred embodiment, hydraulic fluid is fed to each sliding sleeve **75** through a hydraulic tube bundle (not shown) which runs down the annulus between the wellbore **1** and the tubing string **38**. Each of the packers **71** is adapted to pass the hydraulic lines while maintaining a fluid seal. Likewise, at least one optical fiber **15** is run in the annulus to each of the sliding sleeves **75**. The optical fibers may be run in a separate bundle or they may be included in the bundle with the hydraulic lines. The optical fiber **15** is terminated, at the surface in an optical system **17** which contains the optical source and analysis equipment as will be described. In one preferred embodiment, the optical system **17** comprises a light source and a spectral analyzer (see **Figures 4-7**). In another preferred embodiment, the optical system **17** comprises an optical time domain reflectometer (see **Figures 8-9**). The optical system **17** outputs

a conditioned signal to a controller **100** which uses the information to control the well. The controller **100** contains a microprocessor and circuitry to interface with the optical system **17** and to control the hydraulic system **109** according to programmed instructions for positioning the sliding sleeves and other flow control devices as desired in the multiple production zones to achieve the desired flows. Such other devices include, but are not limited to, downhole safety valves, downhole chokes, and downhole tool stop systems and are described in U.S. Patent 5,868,201, assigned to the assignee of this application, and is hereby incorporated herein by reference.

It will be appreciated by those skilled in the art that, in another preferred embodiment, an intelligent well control system controls the flow control devices such as sliding sleeve **75**. In such a system, the flow control devices are powered by a downhole electro-mechanical driver (not shown) and the optical system **17** may be contained in a downhole controller (not shown). Such a downhole control system is described in **U.S. Patent 5,975,204**, assigned to the assignee of this application, and is hereby incorporated herein by reference.

Figure 2 is a schematic section of sliding sleeve valve assembly, also commonly referred to as a sliding sleeve, **75**. Housing **110** is attached on an upper end to the production string (not shown). As previously indicated in **Figure 1**, the production string is sealed to the wellbore above and below the sliding sleeve by packers **71**. In this preferred embodiment, housing **110** has multiple slots **135** arranged around a section of the housing **110**. A flow control member, or sliding spool, **155** is disposed inside of housing **110** and has multiple slots **120**. Spool **155** has elastomeric seals **125** arranged to seal off flow of formation fluids **145** when spool **155** is in the shown closed position. Spool **155** is driven by a surface controlled hydraulic powered shifting mechanism (not shown). Such hydraulic shifting devices are common in downhole tools and are not discussed further. Alternatively, spool **155** may be driven by an electro-mechanical actuator (not shown).

Housing **110** has an internal longitudinal groove **130**. Disposed in longitudinal slot **130** is optical fiber **15** and microbend elements **31** and **32**. The optical fiber **15** has Bragg gratings written onto the fiber **15** at positions of interest. The operation of the Bragg gratings and microbend elements is discussed below. The optical fiber **15** and microbend elements **31, 32** are potted in groove **130** using a suitable elastomeric

or epoxy material. The potted groove is blended with the internal diameter of housing **110** such that seals **125** effect a fluid seal with the housing **110**. Microbend elements **31** and **32** induce a microbend in the optical fiber **15** when the elements are actuated. This microbend creates a optical loss at the point of the microbend which can be detected using optical techniques as will be discussed below in more detail. Microbend elements can be mechanically and magnetically actuated devices. Mechanical microbend elements are known in the art of fiber optic sensors and will not be discussed further. A type of magnetically actuated microbend element is discussed later. The elements **31, 32** are actuated by engagement with an external member, also termed an actuator, **30** attached at a predetermined location on the periphery of spool **155**. External member **30** may be a continuous annular rib or, alternatively, a button type attachment to spool **155**. In a preferred embodiment, the external member **30** engages only one microbend element at a time. In another preferred embodiment, external member **30** extends longitudinally along spool **155** such that external member **30** continues to engage each previously engaged microbend element as the spool **155** moves from the closed position to the open position. It will be appreciated that as many microbend elements may be disposed along the optical fiber **15** as there are positions of interest of spool **155**.

In another preferred embodiment, optical time domain reflection techniques are used to determine the location of the microbend. Optical time domain reflection techniques are discussed below.

Referring to **Figures 2** and **4** an optical fiber **15** is embedded in the housing **110** with microbend elements **31** and **32** located at positions along the fiber **15** corresponding to positions of interest of the spool **155**. A Bragg grating is written into the fiber **15** next to each of the microbend elements **31** and **32** using techniques known in the art. A person skilled in the art would appreciate how the optical fiber Bragg grating is used as a sensor element. Each fiber Bragg grating is a narrowband reflection filter permanently imparted into the optical fiber. The filter is created by imparting gratings formed by a periodic modulation of the refractive index of the fiber core. The techniques for modulating the index are known in the art. The reflected wavelength is determined by the internal spacing of the grating as seen generally in **Figures 3a-3d**. Light is partially reflected at each grating, with maximum reflection

when each partial reflection is in phase with its neighbors. This occurs at the Bragg wavelength, W_b= 2nd, where n is the average refractive index of the grating and d is the grating spacing. In this invention, each grating has a different predetermined spacing and therefore each grating will reflect a different predetermined wavelength of light. Such gratings are commercially available. By using a different predetermined wavelength for each grating, the reflected light can be spectrally analyzed to determine the wavelength and amplitude of the reflected signal from each grating along the optical fiber.

In general, the microbend elements are actuated by an external member, which may be an annular band or alternatively a button, on the sliding spool **155** as it passes each microbend element. As the microbend element is actuated it imparts a bend in the optical fiber **15**, creating an optical power loss through the optical fiber **15** at the point of the bend. By analyzing the amplitude and wavelength of the reflected light from the various gratings, the position of the actuated microbend element can be determined.

Figures 2 and **4** shows a preferred embodiment of a two position sensor for determining if a sliding sleeve is opened or closed. An optical fiber **15** is disposed in a tubular housing **110** containing sliding spool **155** and external member **30**. Microbend element **31** is located along the optical fiber **15** and is positioned to indicate one limit of the travel of spool **155** when engaged by external member **30**. External member **30** is sized to engage only one microbend sensor at a time. Similarly, microbend element **32** is located to indicate the other limit of the travel of spool **155**.

Bragg gratings **20** and **21** are written onto the optical fiber **15** proximate microbend element **31**. Bragg grating **20** is located between light source **10** and microbend element **31** and acts as a baseline reference for indicating the baseline optical power reflection without the effects of the microbend elements. Grating **21** is written on the optical fiber **15** just downstream of the microbend element **31**. As used herein, upstream refers to the direction towards the light source **10**, and downstream refers to the direction away from the light source **10**. Grating **22** is located proximate to and downstream of microbend element **32**. The fiber end **25** of optical fiber **15** is terminated in an anti-reflective manner so as to prevent interference with the

reflective wavelengths from the Bragg gratings. The fiber end **25** may be cleaved at an angle so that the end face is not perpendicular to the fiber axis. Alternatively, the fiber end **25** may be coated with a material that matches the index of refraction of the fiber, thus permitting light to exit the fiber without back reflection. Light reflected from the gratings travels back toward the light source **10** and is input to spectral analyzer **11** by fiber coupler **12**. Spectral analyzer **11** determines the reflected optical power and wavelength of the reflected signals.

Still referring to **Figure 4**, it can be seen that external member **30** is engaged with microbend element **32** thereby creating a bend in the optical fiber **15** at that location. The bend at the location of element **32** causes a loss in optical power transmitted downstream of element **32**. In operation light source **10** transmits a broadband light signal down optical fiber **15**. The signal is reflected by grating **20** at wavelength **20w** and power level **20p** thereby establishing a baseline for comparison with the downstream grating reflections. Since microbend element **31** is not actuated the light travels relatively undiminished to grating **21** where wavelength **21w** is reflected at power level **21p**. In **Figure 4**, the power levels **20p** and **21p** are essentially equal. The light signal continues down the optical fiber **15** and encounters actuated microbend element **32** which causes an attenuated light signal to be transmitted downstream to grating **22**. Grating **22** reflects wavelength **22w** at a diminished power level **22p**, relative to power levels **20p** and **21p**. The reflected signals are analyzed by spectral analyzer **11** and the resulting signals are shown in **Figure 4** where the engaged power level **22p** from grating **22** is measurably less than the power levels **20p** and **21p** from gratings **20** and **21** respectively. The relative power levels and wavelengths are sent to a processing unit **100** which determines according to programmed instructions and the predetermined locations of the microbend elements and the gratings, the spool **155** position.

Figure 5 shows a preferred embodiment for determining multiple positions of a sliding spool. This embodiment is similar to the two position system. As shown in **Figure 5**, microbend elements **31, 32, 33 and 34** with associated gratings **21, 22, 23 and 24** respectively, each with a unique predetermined wavelength **21w-24w** are disposed at predetermined positions of interest along optical fiber **15**. Note that a

greater or fewer number of pairs of microbend elements and gratings could be located along the optical fiber **15**.

Bragg grating **20** is placed upstream of element **31** and serves as a baseline reference of reflected power. As shown in Figure 5, external member **30** on sliding spool **155**, is engaged with microbend element **33** thereby bending optical fiber **15** at that location. As previously indicated, the bending of optical fiber **15** by microbend element **33** causes a loss of optical power to be transmitted downstream of element **33**. Therefore, as shown in **Figure 5**, the optical power **23p** and **24p** reflected from the gratings **23** and **24**, which are downstream of element **33** are measurably lower than the power levels **20p, 21p** and **22p** measured upstream of element **33**. The reflected signals are analyzed with spectral analyzer **11** and the resulting power levels at the predetermined wavelengths are sent to a processing unit which determines the location of the sliding spool **155** from the predetermined locations of the microbend elements and gratings.

Figure 6 shows another preferred embodiment for determining multiple positions of a sliding sleeve. In this preferred embodiment, multiple microbend elements **31, 32, 33** and **34** are disposed at predetermined positions of interest along optical fiber **15**. Each microbend element is adapted to induce a unique microbend in optical fiber **15**. Each microbend element, therefore, has associated with it a unique optical power loss. Reference grating **20** with wavelength **20w** is located along the optical fiber **15** upstream of the microbend elements. Grating **24** is located downstream of the microbend elements.

As shown in **Figure 6**, the sliding spool external member **30** is engaged with microbend element **33**. Element **33** imposes a unique microbend on optical fiber **15** resulting in a uniquely measurable power transmission which is detected by measuring the reflected power from grating **24** at wavelength **24w** as shown by reflected signal **24r** in **Figure 6**. The amplitude of signal **24r** corresponds to the unique characteristic transmission of element **33**. Note that while the unique power levels shown for each microbend element are monotonically decreasing, this is not a requirement. It is only necessary that each microbend element have a transmission loss that is measurably unique.

Figure 7 shows yet another preferred embodiment for determining multiple positions of a sliding sleeve. Here, each of microbend elements **131, 132, 133** and **134** creates a uniform optical loss in optical fiber **15** when actuated by spool external member **30**. Spool external member **30** is adapted to continue to engage each microbend element after the sleeve has passed said element. As shown in **Figure 7**, sleeve external member **30** is engaging microbend element **133** and continues to engage element **134**. Each engaged element uniformly decreases the optical power transmitted down the optical fiber **15** and hence decreases the optical power reflected by grating **24** and sensed by analyzer **11**. The power level detected is transmitted to processor **100** which determines the sleeve location from the predetermined positions of the microbend elements **131, 132, 133, 134** and predetermined uniform loss through each actuated microbend element. It will be appreciated that a greater or fewer number of microbend elements may be employed depending on the number of sliding spool positions of interest to be detected.

Figure 8 shows a preferred embodiment of a fiber optic sliding sleeve position indicator using optical time domain reflection techniques to measure the time of flight of an optical signal as it is reflected from a microbend in an optical fiber. The physical arrangement is similar to the previously described position indicators, however, no Bragg gratings are used to characterize the reflected signal. As shown, microbend elements **31, 32, 33, 34** are disposed along optical fiber **15** at predetermined locations of interest, with element **33** engaged and actuated by spool external member **30**. Element **33** creates a microbend in optical fiber **15**. As is known in the art, the microbend in optical fiber **15** will generate a reflection point for light traveling along optical fiber **15**. Optical time domain reflectometer (OTDR) **90** generates a light signal which travels down the optical fiber **15** and a portion of the light signal is reflected by the microbend created at element **33**. The reflected signal is sensed at OTDR **90** and the time for the signal to reach the microbend and return is measured. This time of flight and the predetermined optical properties of optical fiber **15** are input to processor **100** which determines according to programmed instructions which microbend element has been actuated. Optical time domain reflectometers are commercially available and are used extensively in determining the position of anomalies in fiber optic transmission lines.

Figure 9 shows another preferred embodiment using a fiber optic technique to determine the position of a sliding sleeve. Optical fiber **15** is directly engaged by spool external member **30** which creates an optical microbend **91** in optical fiber **15**. The microbend **91** causes a discrete reflection of light traveling down the optical fiber **15**. OTDR **90** generates a light signal which travels down optical fiber **15** and is partially reflected at microbend **91**. The reflected signal is detected by OTDR **90** and the time of flight to the reflection point at microbend **91** and back is determined. The time of flight and the predetermined optical properties of optical fiber **15** are input to processor **100** which determines the location of the microbend **91** along the optical fiber **15**.

Figure 10 shows another preferred embodiment using an optical encoding technique to determine the position of a sliding sleeve valve. Encoding reader **220** is disposed in housing **200** such that it scans the outer surface of flow control member, or spool, **210** as spool **210** moves axially relative to housing **200**. A predetermined pattern of position encoding marks **215** are disposed on the outer surface of spool **210** and are detected by reader **220** as the spool **210** moves. Signals from reader **220** are transmitted to the surface processor **100** for determining the spool **210** position. **Figure 11** shows one preferred pattern of linear encoding marks **230-235** axially disposed on the outer surface of spool **210**. Marks **230-235** may be disposed on the outer surface of spool **210** by machining techniques, photo-etching techniques, or photo-printing techniques common in the manufacturing arts. Marks **230-235** may be protrusions from the outer surface of spool **210**, depressions in the surface, or essentially even with the surface. Marks **230-235** may be coated with reflective materials or paints to enhance detection by reader **220**. The marks **230-235** are positioned to pass through the scanning view of reader **220** as spool **210** moves axially. The overlapping of the marks **230-235** result in the discrete position readings **241-150** as indicated in **Figure 11**. It will be appreciated that different numbers and overlapping patterns of marks can result in different numbers of discrete positions. The position of the spool **210** can be determined to within the resolution of the encoding pattern used.

Figure 12 shows another preferred embodiment using an optical encoding technique to determine the position of a sliding sleeve valve. An optical grating **325** is

disposed on the outer surface of spool **310**. The spacing "L" between adjacent grating lines changes with axial location along the spool **310**. An optical source **315** illuminates the gratings **325** and the reflected pattern is read by optical detector **320** mounted in the wall of housing **300**. Optical source **315** and optical detector **320** may be integrated into a single module or alternatively may be separate modules. The variation in spacing L may be continuous or, alternatively, discrete sections (not shown) of spool **310** may each have a unique spacing (not shown).

Figure 13 shows another preferred embodiment using an optical-magnetic technique to determine the position of a sliding sleeve valve. Using a physical configuration as shown in **Figure 2,** magnetic responsive elements **420, 421, 422, 423, and 424** are located at predetermined positions along and are engaged with optical fiber **415**. A magnet **430,** such as a rare-earth magnet is mounted on sliding sleeve spool **155**. Magnetic responsive microbend elements **420-424** are constructed of magneto-strictive materials such that the elements **420-424** create a microbend in optical fiber **415** when an element is juxtaposed with magnet **430**. In one embodiment, each of the elements **420-424** is sized to create a unique microbend and hence a unique optical reflection from each of the elements **420-424** which is detected by measuring the reflected power signal. Alternatively, the elements **420-424** may be adapted to provide an essentially uniform optical reflection from each element. The reflected signal is transmitted to processor **100** which determines the spool location from the predetermined position of the elements **420-424** and the unique reflection associated with each element. The magnetic responsive elements **420-424** can be used as microbend elements for all of the techniques described in **Figures 4-9** using Bragg gratings or time domain reflectometry.

It will be appreciated that the described fiber optic position sensing techniques may be incorporated in other downhole tools where position or proximity sensors are required to indicate the axial motion of one member relative to a second member where the axial motion enables the control of the well. These tools may include, but are not limited to, inflation/deflation tools for packers, a remotely actuated tool stop, a remotely actuated fluid/gas control device, a downhole safety valve, and a variable choke actuator. These tools are described in U.S. Patent 5,868,201 previously incorporated herein by reference.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible. It is intended that the following claims be interpreted to embrace all such modifications and changes.

What is Claimed is:

1. A system for controlling a downhole flow, comprising;
   a. a flow control device in a tubing string in a well, said flow control device having a first member engaged with said tubing string and second member moveable with respect to said first member and acting cooperatively with said first member for controlling the downhole flow through said flow control device;
   b. an actuator for driving said second member;
   c. an optical position sensing system acting cooperatively with said first member and said second member for detecting a position of said second member relative to said first member and generating at least one signal related thereto; and,
   d. a controller receiving said at least one signal and determining, according to programmed instructions, the position of the second member relative to the first member, and driving said actuator to position said second member at a predetermined position for controlling said downhole flow.

2. The system of claim 1, wherein the optical position sensing system comprises;
   i. an optical fiber disposed in the first member;
   ii. a light source for injecting a broadband light signal into said optical fiber;
   iii. a plurality of optical elements disposed along the optical fiber at predetermined positions for reflecting at least a portion of said broadband light signal, each of said optical elements reflecting an optical signal at a different predetermined optical wavelength from any other of said elements;
   iv. a plurality of corresponding microbend elements disposed proximate said optical elements and acting cooperatively with said second member to change an optical transmission characteristic of said optical

fiber when said second member actuates at least one of said microbend elements; and,

v. a spectral analyzer for detecting at least one optical transmission characteristic of interest of said reflected optical signals and generating at least one analyzer signal in response thereto.

3. The system of claim 2, wherein the controller comprises;

i. circuitry for interfacing with and controlling said optical sensor,

ii. circuitry for interfacing with and driving said actuator; and

iii. a microprocessor for acting according to programmed instructions.

4. The system of claim 2, wherein the plurality of microbend elements are mechanically actuated.

5. The system of claim 2, wherein the plurality of microbend elements are magnetically actuated.

6. The system of claim 2, wherein the at least one optical transmission characteristic of interest of said optical signal is at least one of (i) optical power of said reflected optical signal, (ii) wavelength of said reflected optical signal, and (iii) time of flight of said optical signal.

7. The system of claim 1, wherein the well is one of (i) a production well and (ii) an injection well.

8. The system of claim 1, wherein the optical position sensing system comprises;

i. a predetermined pattern of position encoding marks disposed on a surface of the second member, said pattern adapted to provide a position indication of said second member; and,

ii. an optical sensor disposed in the first member for sensing said pattern of position encoding marks and generating a signal related thereto.

9. The system of claim 8, wherein the controller comprises;
   i. circuitry for interfacing with and controlling said optical sensor,
   ii. circuitry for interfacing with and driving said actuator; and
   iii. a microprocessor for acting according to programmed instructions.

10. The system of claim 1, wherein the optical position sensing system comprises;
   i. an optical grating disposed on a surface of the second member, said grating comprising a pattern of lines such that the spacing between adjacent lines is related to axial location along said flow control member; and,
   ii. an optical sensor disposed in the first member for sensing said grating pattern and generating a signal related thereto.

11. The system of claim 10, wherein the controller comprises;
   i. circuitry for interfacing with and controlling said optical sensor,
   ii. circuitry for interfacing with and driving said actuator; and
   iii. a microprocessor for acting according to programmed instructions.

12. The system of claim 2, wherein the plurality of optical elements are Bragg gratings.

13. The system of claim 1, wherein the actuator is at least one of (i) a hydraulic actuator and (ii) an electromechanical actuator.

14. The system of claim 1, wherein the controller is located at one of (i) a surface location and (ii) a downhole location.

15. A sensing system for use in a downhole tool, comprising;
   a. a flow control device in a tubing string in a well, said flow control device having a first member engaged with said tubing string and second member moveable with respect to said first member and acting

cooperatively with said first member for controlling the downhole flow through said flow control device;

b. an optical position sensing system acting cooperatively with said first member and said second member for detecting a position of said second member relative to said first member and generating at least one signal related thereto; and,

c. a controller receiving said at least one signal and determining, according to programmed instructions, the position of the second member relative to the first member.

16. The system of claim 15, wherein the optical position sensing system comprises;

i. an optical fiber disposed in the first member;

ii. a light source for injecting a broadband light signal into said optical fiber;

iii. a plurality of optical elements disposed along the optical fiber at predetermined positions for reflecting at least a portion of said broadband light signal, each of said optical elements reflecting an optical signal at a different predetermined optical wavelength from any other of said elements;

iv. a plurality of corresponding microbend elements disposed proximate said optical elements and acting cooperatively with said second member to change an optical transmission characteristic of said optical fiber when said second member actuates at least one of said microbend elements; and,

v. a spectral analyzer for detecting at least one optical transmission characteristic of interest of said reflected optical signals and generating at least one analyzer signal in response thereto.

17. The system of claim 16, wherein the controller comprises;

i. circuitry for interfacing with and controlling said optical position sensing system,

ii. circuitry for interfacing with and driving said actuator; and

iii. a microprocessor for acting according to programmed instructions.

18. The system of claim 16, wherein the plurality of microbend elements are mechanically actuated.

19. The system of claim 16, wherein the plurality of microbend elements are magnetically actuated.

20. The system of claim 16, wherein the at least one optical transmission characteristic of interest of said optical signal is at least one of (i) optical power of said reflected optical signal, (ii) wavelength of said reflected optical signal, and (iii) time of flight of said optical signal.

21. The system of claim 15, wherein the well is one of (i) a production well and (ii) an injection well.

22. The system of claim 15, wherein the optical position sensing system comprises;

i. a predetermined pattern of position encoding marks disposed on a surface of the second member, said pattern adapted to provide a position indication of said second member; and,

ii. an optical sensor disposed in the first member for sensing said pattern of position encoding marks and generating a signal related thereto.

23. The system of claim 22, wherein the controller comprises;

i. circuitry for interfacing with and controlling said optical sensor,

ii. circuitry for interfacing with and driving said actuator; and

iii. a microprocessor for acting according to programmed instructions.

24. The system of claim 15, wherein the optical position sensing system comprises;

    i. an optical grating disposed on a surface of the second member, said grating comprising a pattern of lines such that the spacing between adjacent lines is related to axial location along said flow control member; and,

    ii. an optical sensor disposed in the first member for sensing said grating pattern and generating a signal related thereto.

25. The system of claim 24, wherein the controller comprises;

    i. circuitry for interfacing with and controlling said optical sensor,

    ii. circuitry for interfacing with and driving said actuator; and

    iii. a microprocessor for acting according to programmed instructions.

26. The system of claim 16, wherein the plurality of optical elements are Bragg gratings.

27. The system of claim 15, further comprising an actuator wherein the actuator is at least one of (i) a hydraulic actuator and (ii) an electromechanical actuator.

28. The system of claim 15, wherein the controller is located at one of (i) a surface location and (ii) a downhole location.

29. A method for determining the position of a moveable second member relative to a first member in a well flow control tool, comprising:

    a. sensing the position of said second member using an optical position sensing system, said optical sensing system generating a signal related to said second member position;

    b. transmitting said signal to a controller; and,

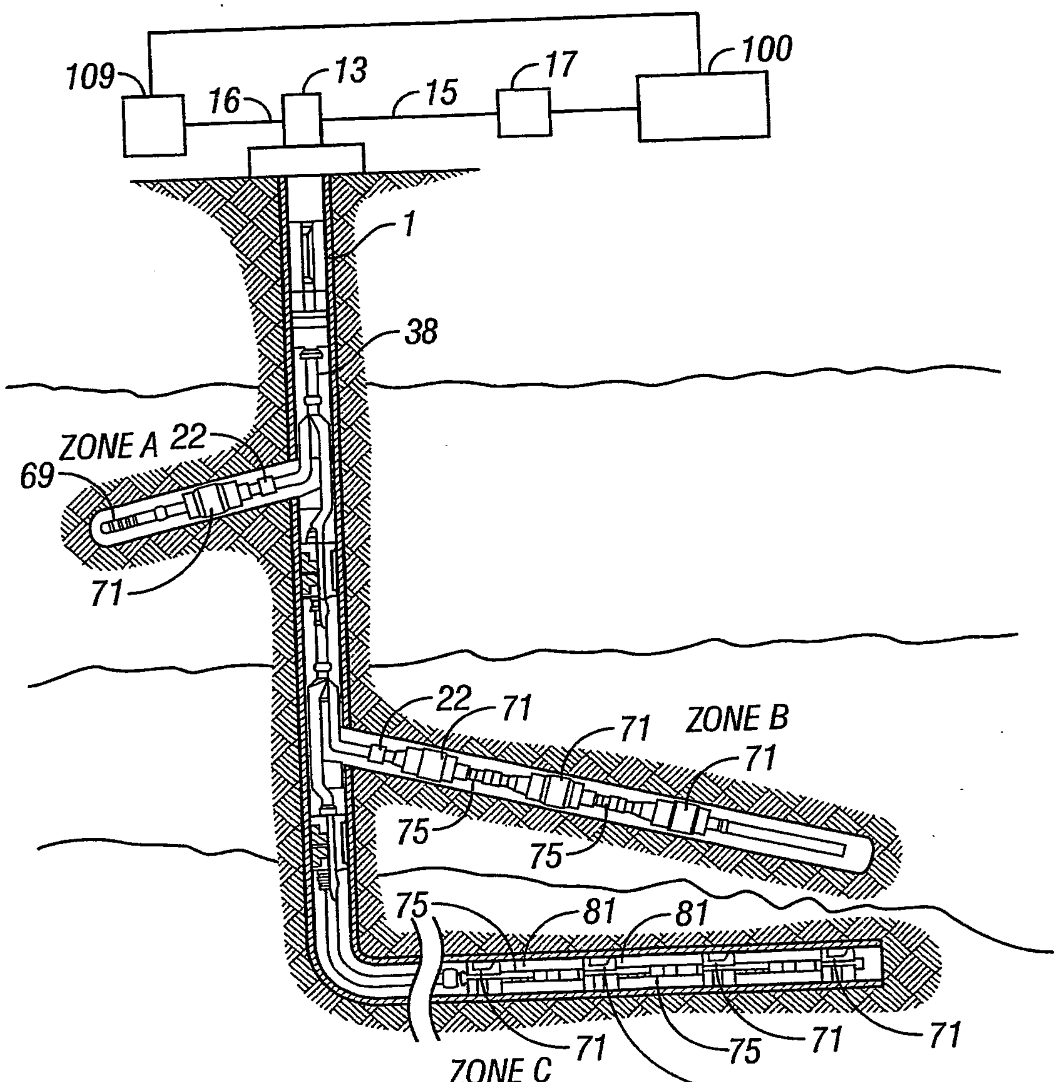
    c. determining, according to programmed instructions, the position of said second member relative to said first member.

30. A method for controlling a downhole flow, comprising;

a. deploying a flow control device in a tubing string in a well, said flow control device having a first member engaged with said tubing string and second member moveable with respect to said first member and acting cooperatively with said first member for controlling the downhole flow through said flow control device;

b. optically sensing the position of said second member with respect to said first member and generating at least one signal related thereto; and,

c. using a controller for receiving said at least one signal and determining, according to programmed instructions, the position of the second member relative to the first member, and driving said actuator to position said second member at a predetermined position for controlling said downhole flow.



109
16
13
15
17
100
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ZONE A
22
69
71
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ZONE B
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81
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71
71
ZONE C

FIG. 1

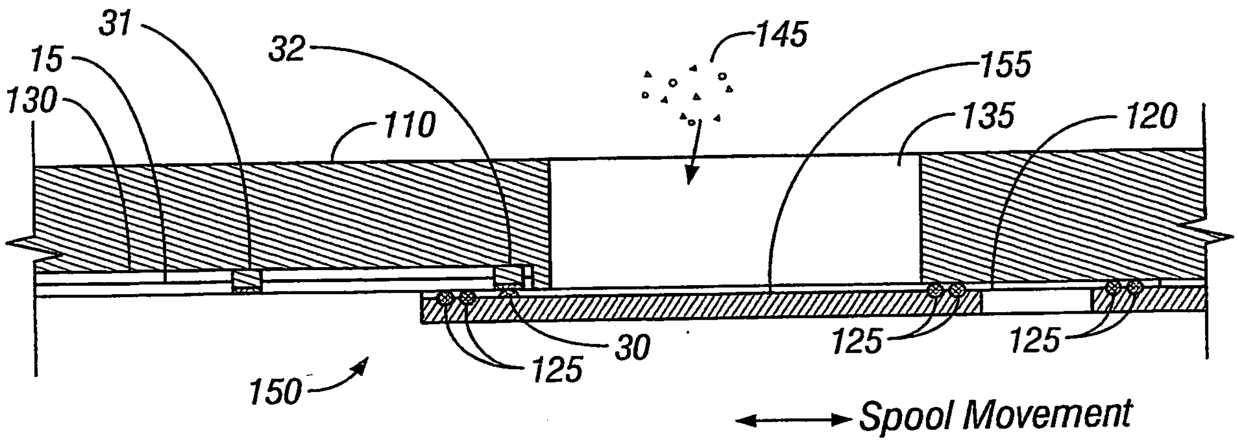


FIG. 2

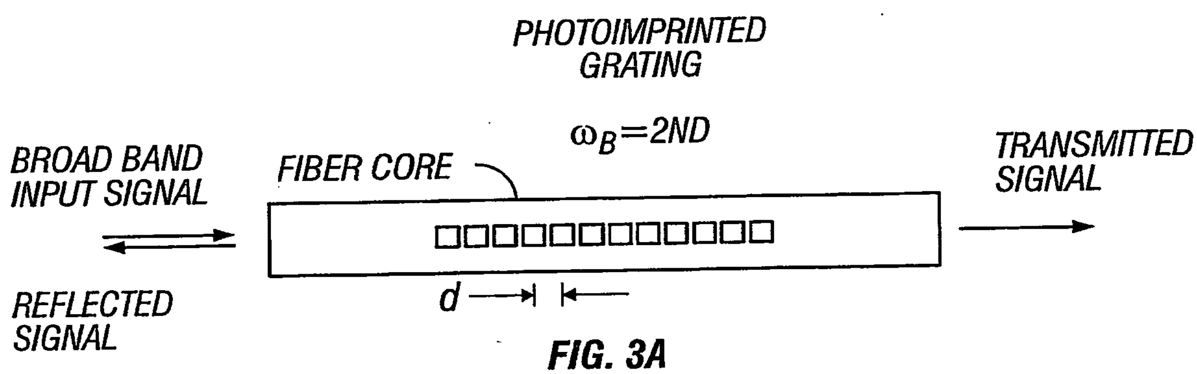


FIG. 3A

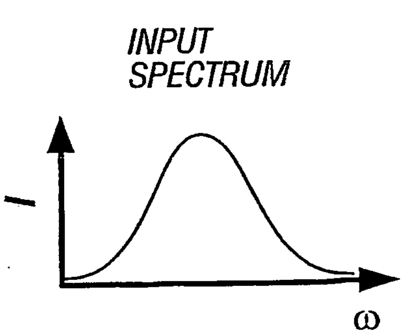


FIG. 3B

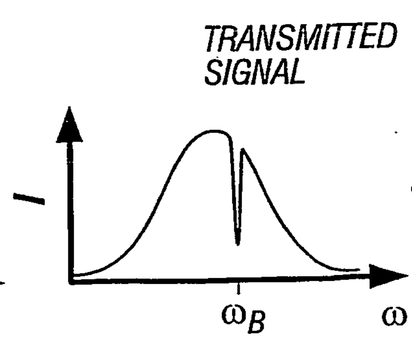


FIG. 3C

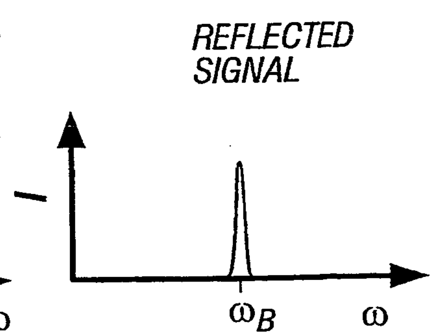
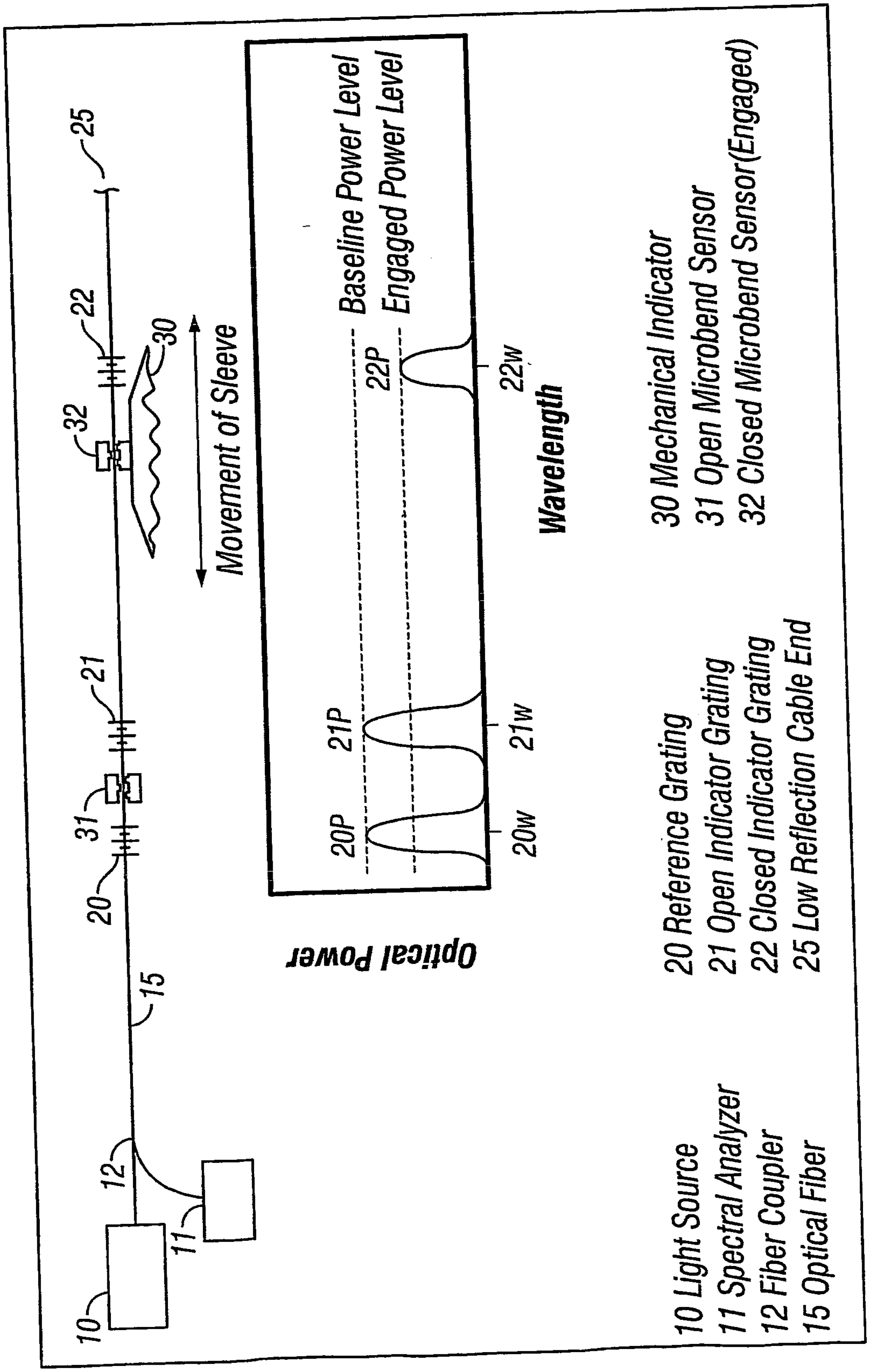


FIG. 3D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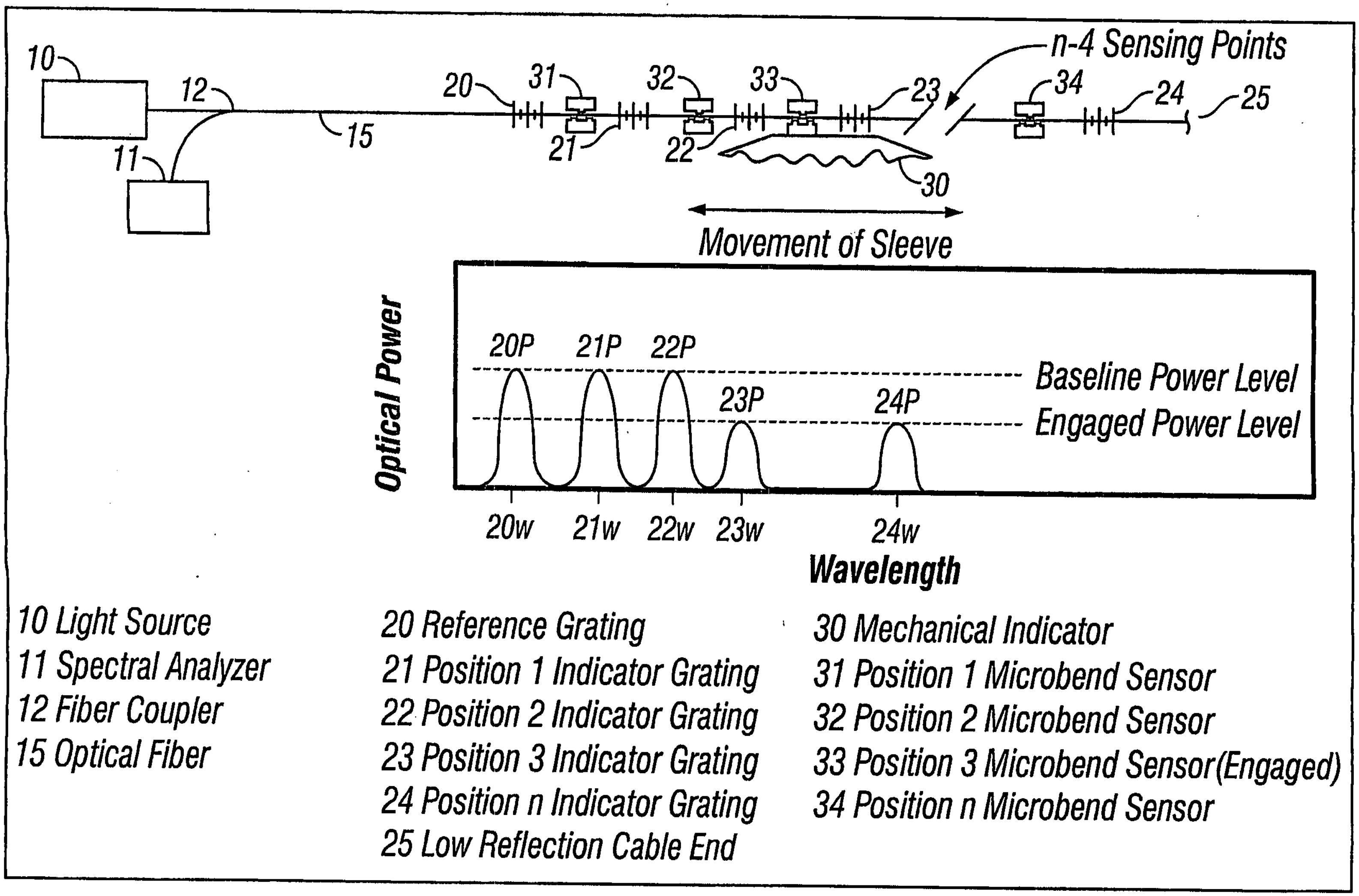
25
Movement of Sleeve
Optical Power
20P
21P
22P
20W
21W
22W
Baseline Power Level
Engaged Power Level
Wavelength
10 Light Source
11 Spectral Analyzer
12 Fiber Coupler
15 Optical Fiber
20 Reference Grating
21 Open Indicator Grating
22 Closed Indicator Grating
25 Low Reflection Cable End
30 Mechanical Indicator
31 Open Microbend Sensor
32 Closed Microbend Sensor(Engaged)

FIG. 4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n-4 Sensing Points
Movement of Sleeve
Optical Power
20P
21P
22P
23P
24P
Baseline Power Level
Engaged Power Level
20w
21w
22w
23w
24w
Wavelength
10 Light Source
11 Spectral Analyzer
12 Fiber Coupler
15 Optical Fiber
20 Reference Grating
21 Position 1 Indicator Grating
22 Position 2 Indicator Grating
23 Position 3 Indicator Grating
24 Position n Indicator Grating
25 Low Reflection Cable End
30 Mechanical Indicator
31 Position 1 Microbend Sensor
32 Position 2 Microbend Sensor
33 Position 3 Microbend Sensor(Engaged)
34 Position n Microbend Sensor

FIG. 5

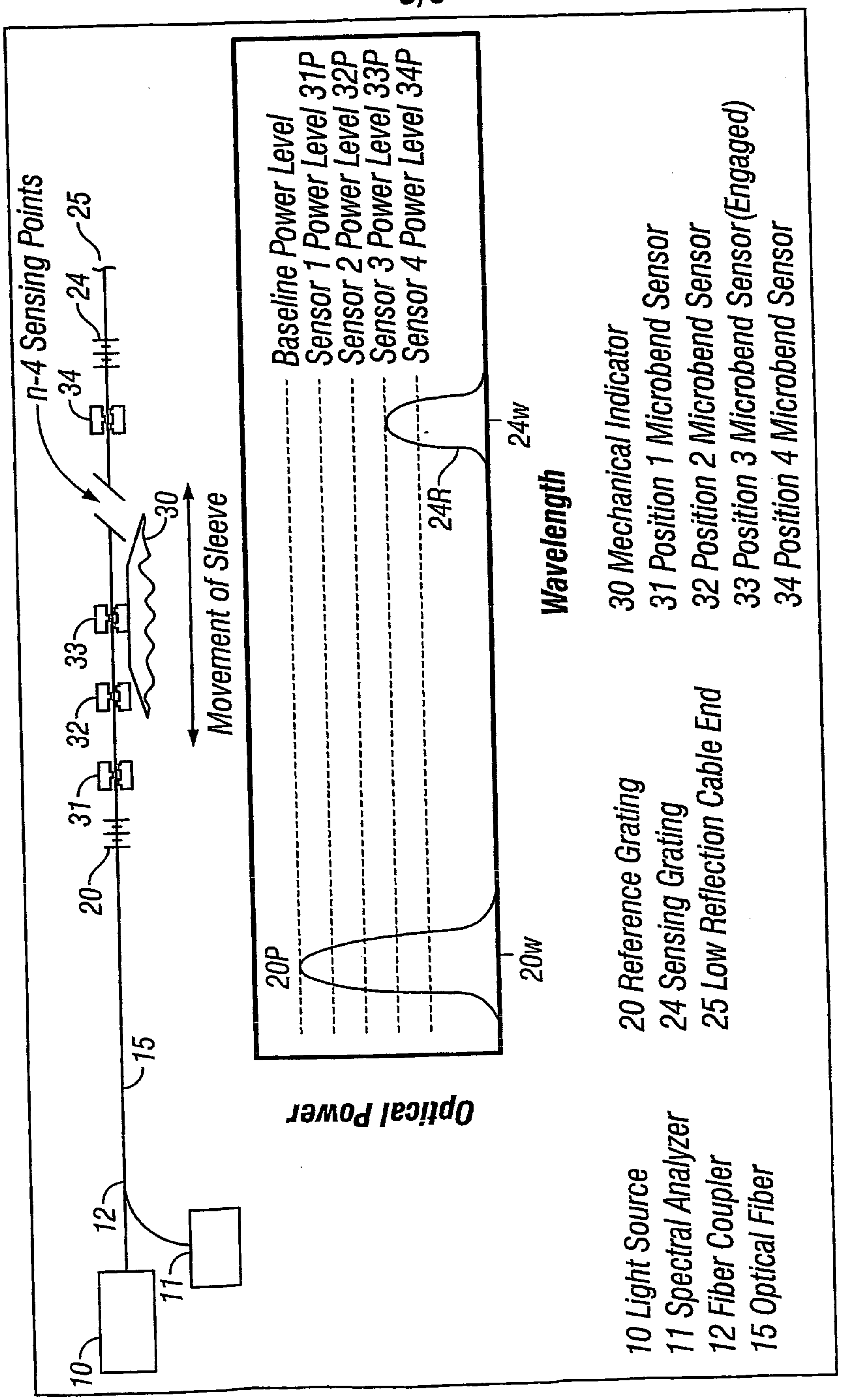
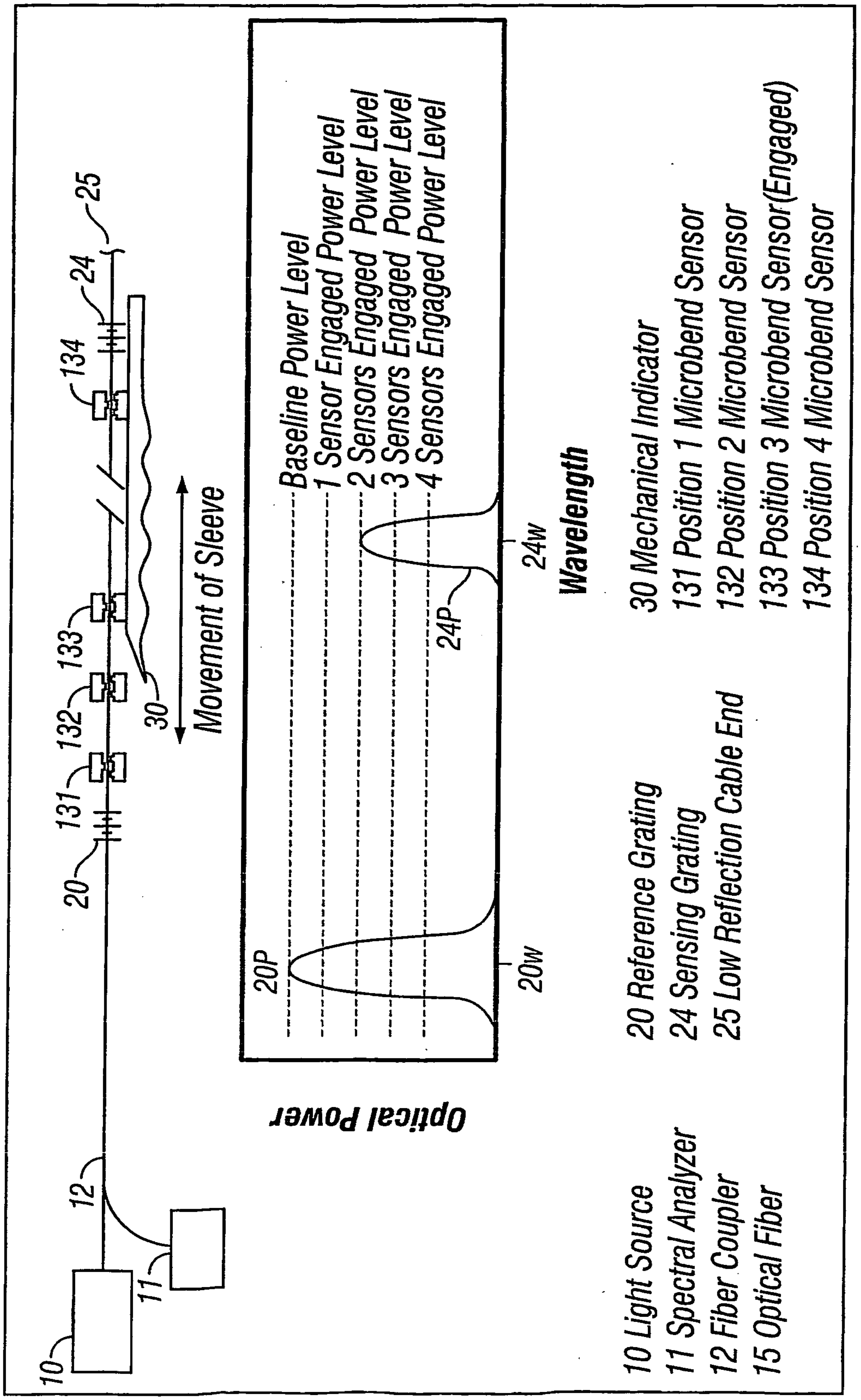

n-4 Sensing Points
10
11
12
15
20
31
32
33
30
34
24
25
Movement of Sleeve
Optical Power
20P
20w
24R
24w
Baseline Power Level
Sensor 1 Power Level 31P
Sensor 2 Power Level 32P
Sensor 3 Power Level 33P
Sensor 4 Power Level 34P
Wavelength
10 Light Source
11 Spectral Analyzer
12 Fiber Coupler
15 Optical Fiber
20 Reference Grating
24 Sensing Grating
25 Low Reflection Cable End
30 Mechanical Indicator
31 Position 1 Microbend Sensor
32 Position 2 Microbend Sensor
33 Position 3 Microbend Sensor(Engaged)
34 Position 4 Microbend Sensor

FIG. 6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11
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20
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133
134
24
25
30
Movement of Sleeve
Optical Power
20P
24P
20W
24W
Wavelength
Baseline Power Level
1 Sensor Engaged Power Level
2 Sensors Engaged Power Level
3 Sensors Engaged Power Level
4 Sensors Engaged Power Level
10 Light Source
11 Spectral Analyzer
12 Fiber Coupler
15 Optical Fiber
20 Reference Grating
24 Sensing Grating
25 Low Reflection Cable End
30 Mechanical Indicator
131 Position 1 Microbend Sensor
132 Position 2 Microbend Sensor
133 Position 3 Microbend Sensor(Engaged)
134 Position 4 Microbend Sensor

FIG. 7

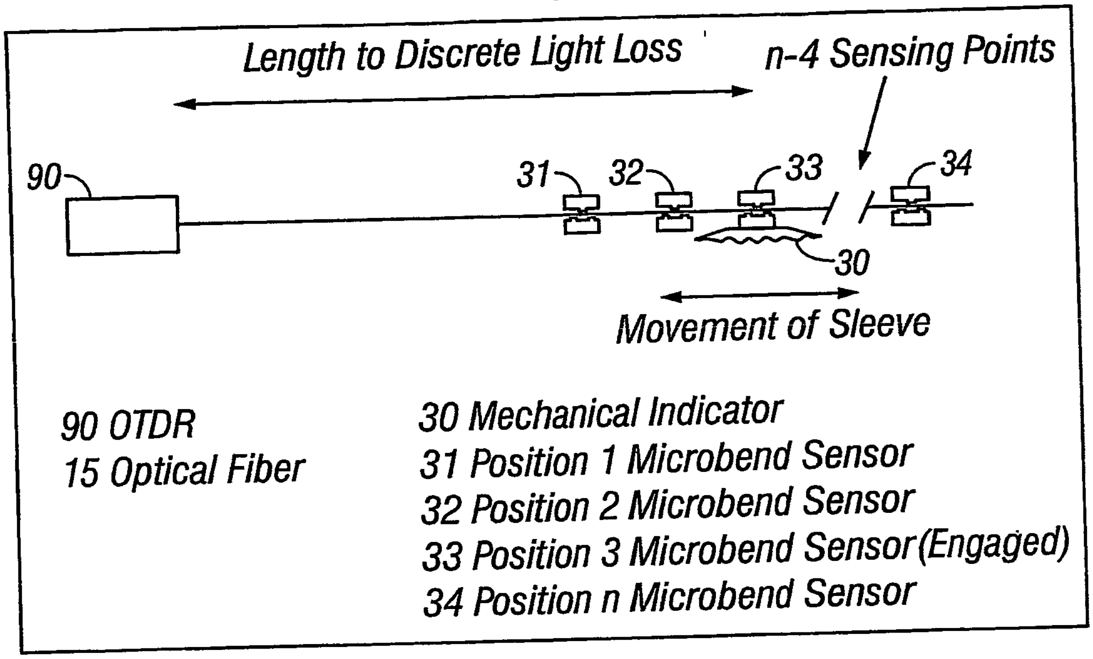
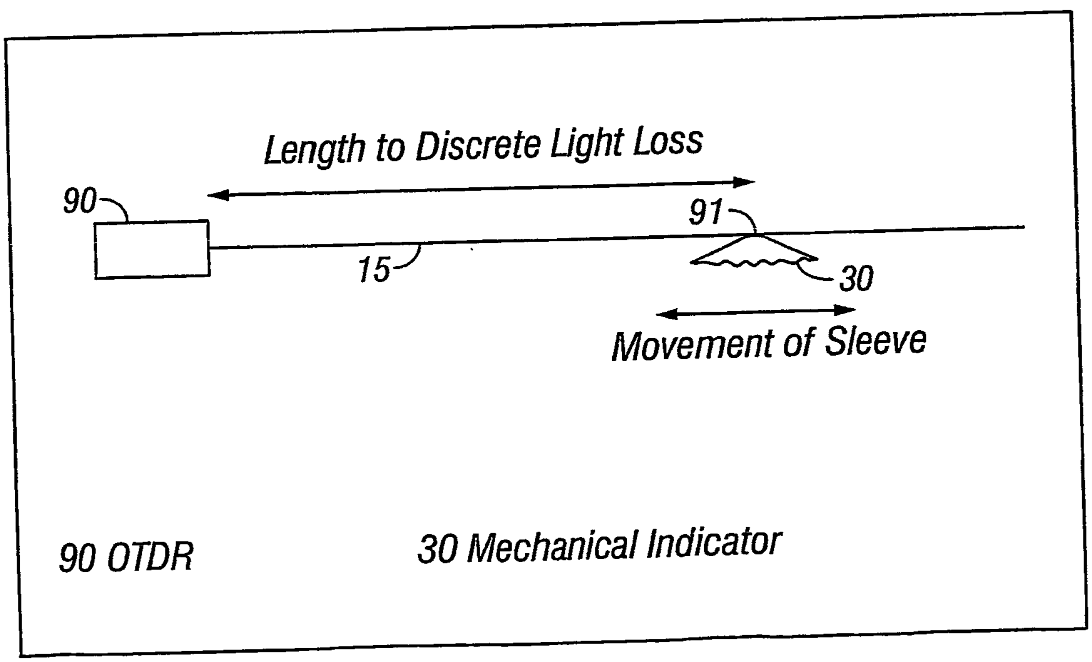

Length to Discrete Light Loss
n-4 Sensing Points
90
31
32
33
34
30
Movement of Sleeve
90 OTDR
15 Optical Fiber
30 Mechanical Indicator
31 Position 1 Microbend Sensor
32 Position 2 Microbend Sensor
33 Position 3 Microbend Sensor(Engaged)
34 Position n Microbend Sensor

FIG. 8


Length to Discrete Light Loss
90
91
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Movement of Sleeve
90 OTDR
30 Mechanical Indicator

FIG. 9

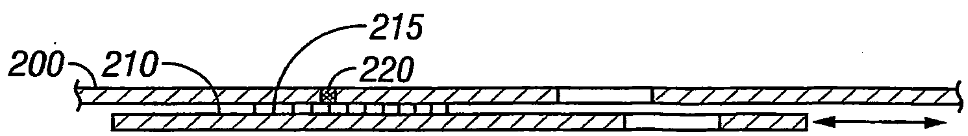


FIG. 10

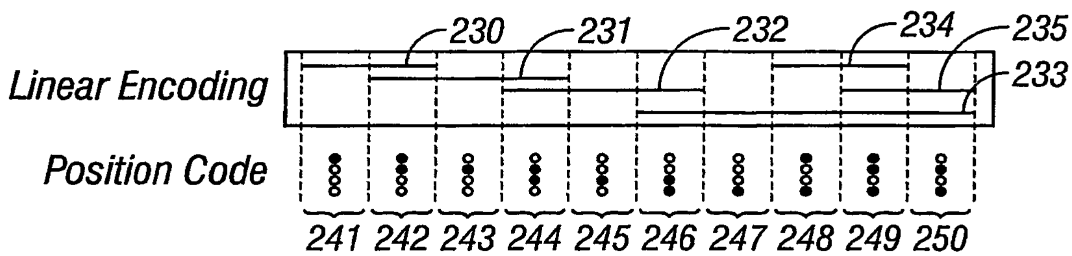


FIG. 11

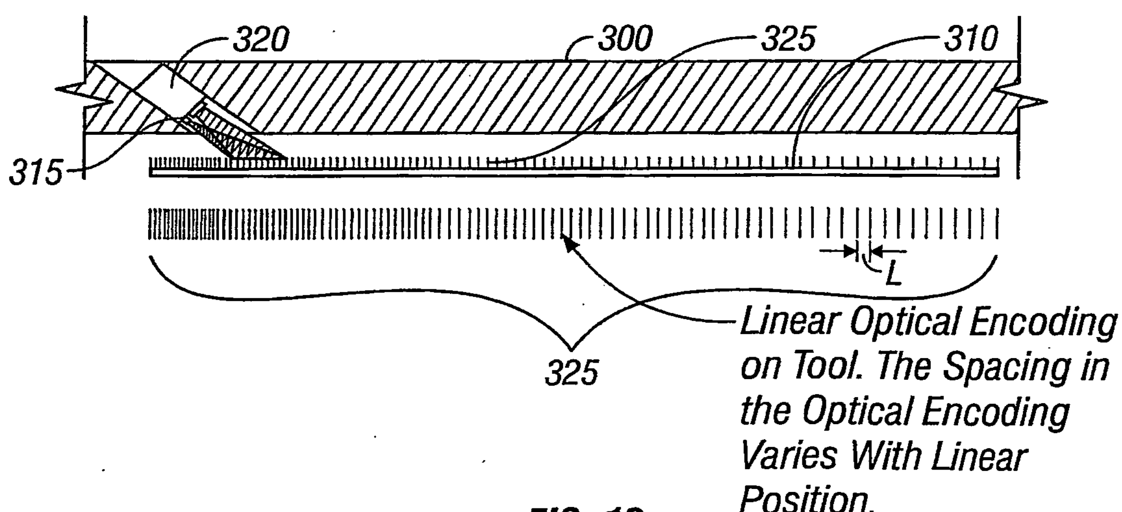
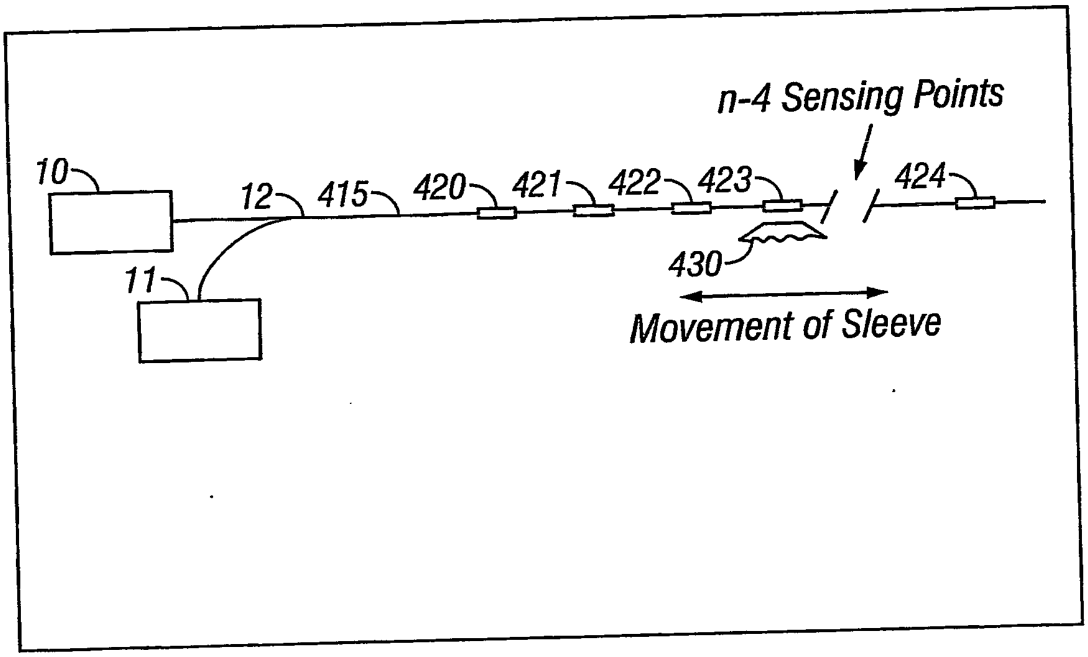


FIG. 12


n-4 Sensing Points
10
12
415
420
421
422
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424
11
430
Movement of Sleeve

FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/36080

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B47/09 E21B47/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, TULSA, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2001/013412 A1 (TUBEL PAULO) 16 August 2001 (2001-08-16) page 16, paragraphs 177-179 figures 6,7,13	1,7, 13-15, 21,27-30
Y	WO 01 67466 A (EXPRO NORTH SEA LTD ;RICHARDS ANDREW (GB); WEBSTER WILLIAM GEORGE) 13 September 2001 (2001-09-13) claim 9	1,7, 13-15, 21,27-30
A	US 2001/020675 A1 (LEGGETT NIGEL ET AL) 13 September 2001 (2001-09-13) the whole document	1,15,29, 30
A	US 6 004 639 A (NOLET STEPHEN C ET AL) 21 December 1999 (1999-12-21) the whole document	1,15,29, 30

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 February 2003	13/02/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schouten, A

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/36080

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 233 746 B1 (SKINNER NEAL G) 22 May 2001 (2001-05-22) the whole document	1,15,29, 30
A	US 6 009 216 A (PRUETT PHILLIP EDMUND ET AL) 28 December 1999 (1999-12-28) the whole document	1,15,29, 30

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 02/36080

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2001013412 A1	16-08-2001	US 6192988 B1	27-02-2001
		US 5941307 A	24-08-1999
		US 5732776 A	31-03-1998
		US 2002020533 A1	21-02-2002
		AU 708330 B2	05-08-1999
		AU 4980696 A	27-08-1996
		AU 5022396 A	27-08-1996
		CA 2187422 A1	15-08-1996
		CA 2187423 A1	15-08-1996
		GB 2302114 A ,B	08-01-1997
		GB 2302432 A	15-01-1997
		NO 960518 A	12-08-1996
		NO 960527 A	12-08-1996
		US 6192980 B1	27-02-2001
		WO 9624751 A1	15-08-1996
		WO 9624747 A1	15-08-1996
		US 6442105 B1	27-08-2002
		US 6176312 B1	23-01-2001
		US 5975204 A	02-11-1999
WO 0167466 A	13-09-2001	AU 3586201 A	17-09-2001
		EP 1261974 A1	04-12-2002
		WO 0167466 A1	13-09-2001
		NO 20024254 A	23-10-2002
US 2001020675 A1	13-09-2001	US 6281489 B1	28-08-2001
		US 2002109080 A1	15-08-2002
		AU 730715 B2	15-03-2001
		AU 4902297 A	05-05-1998
		AU 753252 B2	10-10-2002
		AU 7273798 A	27-11-1998
		AU 7275398 A	27-11-1998
		EP 0910725 A1	28-04-1999
		GB 2354822 A ,B	04-04-2001
		GB 2354583 A ,B	28-03-2001
		GB 2362462 A ,B	21-11-2001
		GB 2362463 A ,B	21-11-2001
		GB 2364380 A ,B	23-01-2002
		GB 2364381 A ,B	23-01-2002
		GB 2364382 A	23-01-2002
		GB 2364383 A	23-01-2002
		GB 2364384 A	23-01-2002
		GB 2334104 A ,B	11-08-1999
		GB 2339902 A ,B	09-02-2000
		NO 991350 A	19-03-1999
		NO 991667 A	27-05-1999
		NO 995319 A	20-12-1999
		NO 20023857 A	19-03-1999
		US 6268911 B1	31-07-2001
		WO 9815850 A1	16-04-1998
		WO 9850681 A1	12-11-1998
		WO 9850680 A2	12-11-1998
		US 6209640 B1	03-04-2001
		US 6302204 B1	16-10-2001
		US 6253848 B1	03-07-2001
		US 2001023614 A1	27-09-2001
		US 2002066309 A1	06-06-2002
		US 6065538 A	23-05-2000

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 02/36080

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2001020675	A1		AU	742656	B2	10-01-2002
			AU	7501498	A	30-12-1998
			BR	9809998	A	15-01-2002
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			NO	996082	A	08-02-2000
			WO	9857030	A1	17-12-1998
			BR	9902017	A	21-03-2000
US 6004639	A	21-12-1999	CA	2305148	A1	22-04-1999
			GB	2346189	A ,B	02-08-2000
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US 6233746	B1	22-05-2001	NONE			
US 6009216	A	28-12-1999	AU	1377999	A	24-05-1999
			CA	2309620	A1	14-05-1999
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